EXTERNAL MODULAR ANTENNAS AND WIRELESS TERMINALS INCORPORATING THE SAME

FIELD OF THE INVENTION

The present invention relates to the field of communications, and, more particularly, to antennas and wireless terminals incorporating the same.

BACKGROUND OF THE INVENTION

The size of wireless terminals has been decreasing with many contemporary wireless terminals being less than 11 centimeters in length. Correspondingly, there is increasing interest in small antennas that can be utilized as internally mounted antennas for wireless terminals. Inverted-F antennas, for example, may be well suited for use within the confines of wireless terminals, particularly wireless terminals undergoing miniaturization. Typically, conventional inverted-F antennas include a conductive element that is maintained in a spaced apart relationship with a ground plane. Exemplary inverted-F antennas are described in U.S. Patent Nos. 6,538,604 and 6,380,905, which are incorporated herein by reference in their entireties.

Furthermore, it may be desirable for a wireless terminal to operate within multiple frequency bands in order to utilize more than one communications system. For example, Global System for Mobile communication (GSM) is a digital mobile telephone system that typically operates at a low frequency band, such as between 880 MHz and 960 MHz. A Digital Communications System (DCS) is a digital mobile telephone system that typically operates at high frequency bands, such as between 1710 MHz and 1880 MHz. In addition, global positioning systems (GPS) or Bluetooth systems use frequencies of 1.575 or 2.4-2.48 GHz. The frequency bands allocated for mobile terminals in North America include 824-894 MHz for Advanced Mobile Phone Service (AMPS) and 1850-1990 MHz for Personal Communication Services (PCS). Other frequency bands are used in other jurisdictions.

Accordingly, the wireless devices may use antennas configured for operation within multiple frequency bands. Despite the above, certain users may prefer devices with external antennas rather than internal antennas. Accordingly, there remains a need to provide cost-effective alternative antenna configurations that can reflect a user's preference.

SUMMARY OF THE INVENTION

Embodiments of the present invention provide external antennas that can be interchanged, retrofitted, and/or selectively used in place of internal antennas for wireless terminals such as communications devices.

Certain embodiments of the invention are directed toward a modular external antenna assembly that is adapted to replace an internal antenna in a wireless terminal device. The assembly includes a modular antenna housing holding an external antenna and having a shape that is adapted to attach to a predetermined portion of a wireless terminal device that is adapted (in standard operation) to accept, operate with and/or employ an internal antenna.

In particular embodiments, the assembly may include a signal feed positioned in a substantially central top portion of the modular antenna housing so that, in position in the wireless terminal device, the modular external antenna assembly signal feed engages an underlying signal feed of the wireless terminal device that is also configured to electrically connect the internal antenna to the wireless terminal device. The signal feed may be positioned on an inwardly and/or downwardly protruding finger that is sized and configured to automatically connect the modular external antenna to the wireless terminal device signal feed when the modular housing is attached to the wireless terminal device. In certain embodiments, the modular antenna housing is configured to define a portion of a rear cover member of a mobile telephone.

Other embodiments are directed to an after-market internal antenna replacement kit for a wireless terminal device. The kit includes a modular housing with an external antenna held therein. The modular housing is configured and sized to mount to a portion of a predetermined wireless terminal device that is configured to (conventionally) operate with an internal planar inverted F-antenna.

In certain embodiments, the modular antenna housing in the kit can be configured to interchangeably, releaseably attach to the wireless device to replace the rear cover that supports an internal planar inverted F-antenna.

Still other embodiments are directed toward a wireless terminal product. The product includes: (a) a housing having opposing front and back portions, the back portion having a releaseably attachable upper rear panel, the housing configured to enclose a transceiver that transmits and receives wireless communications signals; (b) a ground plane disposed within the housing; (c) a planar inverted-F internal antenna configured and sized to be positioned within the housing and electrically connected with the transceiver, wherein the internal antenna comprises a planar dielectric substrate and a planar conductive element disposed on the planar dielectric substrate, and wherein the internal antenna is integral with a first upper rear panel; (d) an external antenna configured and sized to be positioned within the housing held on a second releaseably attachable upper rear panel member, wherein the first and second upper rear panels with the internal and external antenna, respectively, are configured and sized to be interchangeably attachable to the housing; (e) a signal feed configured to electrically connect to one of the internal and external antennas depending on which of the first and second upper rear panels are in position on the wireless terminal; and (f) a ground feed electrically connected to one of the internal and external antennas depending on which of the first and second upper rear panels are in position on the wireless terminal.

Additional embodiments are directed to methods for retrofitting a wireless device configured to operate with an internal antenna to allow replacement of the internal antenna with an external antenna. The method includes providing a wireless terminal with a housing and an internal antenna and replacing the internal antenna with an external antenna.

In other particular embodiments, the internal antenna (which may be a PIFA antenna) is held on a first rear panel that can be configured to releaseably engage the wireless terminal housing. The external antenna is mounted to a second rear panel that can be configured to releaseably engage the housing. The first and second rear panels can be interchangeably mounted to the wireless housing. The replacing step can be carried out by removing the first panel and then attaching the second panel.

In particular embodiments, the external antenna can be configured to operate at both a high and low frequency band. For example, the external antenna can operate

at a first (low band) frequency of between about 824-894 MHz and at least one-second (high band) frequency of between about 1850-1990 MHz.

These and other embodiments will be described further below.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1A is an exploded top perspective view of a wireless terminal device with an internal antenna according to embodiments of the present invention.

Figure 1B is a partial side cutaway view of a wireless terminal adapted to hold an internal antenna according to embodiments of the present invention.

Figure 2A is a perspective view of the device of **Figure 1A** with an external antenna according to embodiments of the present invention.

Figure 2B is a perspective view of a rear modular panel that can be configured to hold the external antenna on the device shown in **Figure 2A** according to embodiments of the present invention.

Figure 3A is a perspective view of the device of **Figure 1A** with an external antenna according to additional embodiments of the present invention.

Figure 3B and 3C are perspective views of a rear modular panel that can be configured to hold the external antenna on the device shown in **Figure 3A** according to embodiments of the present invention.

Figure 4A is a perspective view of a rear modular panel that can be configured to hold an extendable and retractable external antenna (shown in an extended or partially extended state) and that can be mounted to a wireless terminal such as the device shown in **Figure 1A** according to embodiments of the present invention.

Figure 4B is a perspective view of the device of **Figure 4A** with the external antenna in a retracted state according to embodiments of the present invention.

DETAILED DESCRIPTION OF EMBODIMENTS OF THE INVENTION

The present invention will now be described more fully hereinafter with reference to the accompanying drawings, in which embodiments of the invention are shown. This invention may, however, be embodied in many different forms and should not be construed as limited to the embodiments set forth herein; rather, these embodiments are provided so that this disclosure will be thorough and complete, and will fully convey the scope of the invention to those skilled in the art. Like numbers

refer to like elements throughout. It will be appreciated that although discussed with respect to a certain antenna embodiment, features or operation of one antenna embodiment can apply to others.

In the drawings, the thickness of lines, layers, features, components and/or regions may be exaggerated for clarity. It will be understood that when a feature, such as a layer, region or substrate, is referred to as being "on" another feature or element, it can be directly on the other element or intervening elements may also be present. In contrast, when an element is referred to as being "directly on" another feature or element, there are no intervening elements present. It will also be understood that, when a feature or element is referred to as being "connected" or "coupled" to another feature or element, it can be directly connected to the other element or intervening elements may be present. In contrast, when a feature or element is referred to as being "directly connected" or "directly coupled" to another element, there are no intervening elements present.

The term "external antenna" means that the antenna is disposed or resides, at least partially, on the outside of the wireless terminal housing or body and is, thus, externally visible to a user. The "external" antenna is in contrast to an "internal" antenna, which is held encased inside the wireless terminal housing or body. The term "modular" means that the external antenna housing component or panel (that can hold and/or support the external antenna and electrical connections) is configured with standardized dimensions that allow the external antenna housing component to interchangeably mount to and replace a predetermined portion of a wireless terminal product that is configured to also accept and/or hold therein an internal antenna, typically an internal planar inverted F-antenna. The modular component can be configured to disengage the internal antenna from operation with the external antenna, thereby providing the active antenna for the device. Typically, the external antenna assembly is configured to allow removal of the internal antenna from the wireless terminal device to thereby replace the internal antenna function. The external antenna can be configured for easy mount (such as "snap-in") replacement of a rear panel and to operate at substantially the same resonant frequencies as the internal antenna to allow substantially transparent operational frequency band integration in the device, when properly installed.

Embodiments of the present invention will now be described in detail below with reference to the figures. Antennas according to embodiments of the present

invention may be useful in, for example, multiple mode wireless terminals that support two or more different resonant frequency bands, such as world phones and/or dual mode phones. In certain embodiments, the antennas of the present invention can operate in a low frequency band and a high frequency band. The terms "low frequency band" or "low band" are used interchangeably and, in certain embodiments, include frequencies below about 1 GHz, and typically comprise at least one of 824-894 MHz or 880-960 MHz. The terms "high frequency band" and "high band" are used interchangeably and, in certain embodiments, include frequencies above 1 GHz, and typically frequencies between about 1.5-2.5 GHz. Frequencies in high band can include selected ones or ranges within about 1.700-1.990 GHz, 1.990-2.100 GHz, and/or 2.4-2.485 GHz.

In certain embodiments, the antennas may be configured to provide resonance for a global positioning system (GPS) as the terminal into which this antenna is to be built, and can include a GPS receiver. GPS operates at approximately 1.575 GHz. GPS is well known to those skilled in the art. GPS is a space-based triangulation system using satellites and computers to measure positions anywhere on the earth. Compared to other land-based systems, GPS is less limited in its coverage, typically provides continuous twenty-four hour coverage regardless of weather conditions, and is highly accurate. In the current implementation, a constellation of twenty-four satellites that orbit the earth continually emit the GPS radio frequency. The additional resonance of the antenna as described above permits the antenna to be used to receive these GPS signals.

As used herein, the term "wireless terminal" may include, but is not limited to, a cellular wireless terminal with or without a multi-line display; a Personal Communications System (PCS) terminal that may combine a cellular wireless terminal with data processing, facsimile and data communications capabilities; a PDA that can include a wireless terminal, pager, internet/intranet access, web browser, organizer, calendar and/or a GPS receiver; and a conventional laptop and/or palmtop receiver or other appliance that includes a wireless terminal transceiver. Wireless terminals may also be referred to as "pervasive computing" devices and may be mobile terminals.

It will be understood by those having skill in the art of communications devices that an antenna is a device that may be used for transmitting and/or receiving electrical signals. During transmission, an antenna may accept energy from a

transmission line and radiate this energy into space. During reception, an antenna may gather energy from an incident wave and provide this energy to a transmission line. The amount of power radiated from or received by an antenna is typically described in terms of gain.

Voltage Standing Wave Ratio (VSWR) relates to the impedance match of an antenna feed point with a feed line or transmission line of a communications device, such as a wireless terminal. To radiate radio frequency energy with minimum loss, or to pass along received RF energy to a wireless terminal receiver with minimum loss, the impedance of a wireless terminal antenna is conventionally matched to the impedance of a transmission line or feed point. Conventional wireless terminals typically employ an antenna that is electrically connected to a transceiver operatively associated with a signal processing circuit positioned on an internally disposed printed circuit board. In order to increase the power transfer between an antenna and a transceiver, the transceiver and the antenna may be interconnected such that their respective impedances are substantially "matched," *i.e.*, electrically tuned to compensate for undesired antenna impedance components, to provide a 50-Ohm (Ω) (or desired) impedance value at the feed point.

Referring to **Figures 1A** and **1B**, exemplary conventional devices using internal antennas (typically planar inverted F-antennas) that may be particularly suitable for modular retrofit or upgrade with an external antenna are described. **Figure 1A** illustrates the rear portion **10r** of an exemplary wireless terminal device **10**. The forward portion **10f** typically includes a keypad and/or display (not shown). As shown, the device **10** includes a frame body **10b** and releaseably attachable upper and lower rear panels, **20u**, **20l**, respectively, that mount to the frame body **10b**. The device **10** can be configured to accept an internal antenna assembly **40** with a conductive element **40e** and substrate base **50**. In certain embodiments, the lower panel **20l** may encase a battery or a battery may actually define the lower rear panel **20l**. The upper panel **20u** can be an external cover member **70** that is sized and configured to overlie and encase the internal antenna assembly **40** therein. In other embodiments, the upper panel **20u** is configured as an integrated cover and antenna assembly, in which the antenna cover **70** and antenna assembly **40** are attached to each other and mount to (and release from) the frame **10b** together, typically as a

unitary component. An internal surface of the upper rear panel **20u** may be used to provide the substrate **50** that holds the antenna **40**, such as shown in **Figure 1B**.

The device **10** also includes signal and ground connectors **30**. The signal and ground connectors **30** may be spring-loaded pins or other mechanical configurations that allow electrical interface between the signal feed (typically via an underlying printed circuit board - shown as feature **100** in **Figure 1B**) to the antenna assembly **40**. The signal and ground connectors **30** may also be proximately positioned to each other about a substantially central position of a rear top portion of the device **10** to extend outwardly toward the rear **10r** of the device. Other configurations may also be used.

The internal antenna **40** can be disposed substantially parallel to a ground plane **125 (Figure 1B)** and can be connected to the ground plane **125** and transceiver components **161s** via respective ground and signal feeds. The antenna element **40** may be formed or shaped with a certain size and may reside in a position with respect to the ground plane **125** so as to conform to the shape of the wireless terminal (shown as a radiotelephone terminal housing) or a subassembly therein. For example, the antenna **40** may be placed on a substrate that defines a portion of an enclosed acoustic chamber and/or rear cover or panel **70, 20u** as described above. Thus, the internal antenna **40** may be a planar inverted F-antenna, but not be strictly "planar," although in the vernacular of the art, it may still be referred to as a planar inverted-F antenna.

In addition, it will be understood that although the term "ground plane" as used herein, is not limited to the form of a plane. For example, the "ground plane" may be a strip or any shape or reasonable size and may include non-planar structures such as shield cans or other metallic objects.

The antenna conductive element **40e** may be provided with or without an underlying substrate dielectric backing, such as, for example, FR4 or polyimide. In addition, the antenna **40** may include air gaps in the spaces between the branches or segments. Alternatively, the spaces may be at least partially filled with a dielectric substrate material or the conductive pattern formed over a backing sheet. Furthermore, an inverted-F conductive element, according to embodiments of the present invention, may have been disposed on and/or within a dielectric substrate (which may be the rear panel **20u** and/or cover **70**).

The antenna conductive element **40e** may be formed of copper and/or other suitable conductive material. For example, the conductive element branches may be

formed from a copper sheet. Alternatively, the conductive element branches may be formed from copper layered on a dielectric substrate. However, conductive element branches for inverted-F conductive elements according to the present invention may be formed from various conductive materials and are not limited to copper as is well known to those of skill in the art. The antenna can be fashioned in any suitable manner, including, but not limited to, metal stamping or forming the conductive material in a desired pattern on a flex film or other substrate whether by depositing, inking, painting, etching or otherwise providing conductive material traces onto the substrate material.

Further, as is known to those of skill in the art, matching components may be added to improve the impedance match to a 50-Ohm source and/or to increase bandwidth and low-band gain. For example, adding about 1-3 nH of inductance in series with the feed may improve low-band without significantly influencing high-band.

Referring now to **Figure 1B**, a side-sectional view of an exemplary wireless terminal **10'** is illustrated. As shown, the internal antenna **40** includes a conductive element **40e** that is maintained in spaced apart relationship with a ground plane **125** that is typically held on a printed circuit board **100**. The antenna element **40e** is in communication with a signal feed **61s** and a ground feed **61g** via connectors **30**.

Referring again to **Figure 1B**, a conventional arrangement of electronic components that allow the wireless terminal **10'** to transmit and receive wireless terminal communication signals using an internal antenna **40** will be described in further detail. The same operation can occur when the internal antenna **40** is replaced by an external antenna **140**, as will be described below. As illustrated, the internal antenna **40** (or external antenna **140** as shown in **Figures 2-4**) for receiving and/or transmitting wireless terminal communication signals is electrically connected to transceiver circuitry components **161s**. The components **161s** can include a radio-frequency (RF) transceiver that is electrically connected to a controller such as a microprocessor. The controller can be electrically connected to a speaker that is configured to transmit a signal from the controller to a user of a wireless terminal. The controller can also electrically connected to a microphone that receives a voice signal from a user and transmits the voice signal through the controller and transceiver to a remote device. The controller can be electrically connected to a keypad and display that facilitate wireless terminal operation. The design of the

transceiver, controller, and microphone are well known to those of skill in the art and need not be described further herein.

The wireless communication device **10, 10'** shown in the figures may be a radiotelephone type radio terminal of the cellular or PCS type, which is adapted to selectively allow a user to employ one of an internal antenna **40** and external antenna **140** according to embodiments of the present invention.

As shown in **Figure 1B**, the device **10'** includes the signal feed **61s** that extends from a signal receiver and/or transmitter (*e.g.*, an RF transceiver) comprising electronic transceiver components **161s**. The ground plane **125** serves as the ground plane for the planar inverted-F antenna **40**. The antenna **40** can include wrapped portions **212**, which serve to connect the conductive element **40e** to the signal and ground feeds **61s, 61g**. The ground feed **61g** is connected to the ground plane **125.** The antenna **40** can be installed substantially parallel to the ground plane **125**, subject to form shapes, distortions and curvatures as might be present for the particular application, as previously discussed. The signal feed **61s** can pass through an aperture **214** in the ground plane **125** and is connected to the transceiver components **161s.** The transceiver components **161s**, the ground plane **125**, and the inverted-F antenna **40** can be enclosed in a housing for the wireless (*i.e.*, radiotelephone) terminal. The wireless device **10'** may include other components such as a keypad and display as noted above. The ground plane **125** may be configured to underlie or overlie the antenna **40**.

Turning now to **Figures 2-4**, examples of external antennas **140** held in modular external antenna assemblies **140a** that are suitable to replace or be used in a wireless terminal device **10** instead of an internal antenna **40** will be described. Generally stated, the modular external antenna assemblies **140a** are configured and sized with predetermined dimensions that allow a respective one to be used with a predetermined wireless terminal **10**. In certain embodiments, the external antenna **140** can be configured to provide substantially the same operational resonant frequencies (frequency bands) provided by the internal antenna **40** (typically to provide about quarter-wave and/or half-wave resonance at the desired operational frequencies) so that operation is substantially transparent between the two configurations and performance is not unduly compromised (and may be improved) when using the external antenna **140** instead of the internal antenna **40**. The first panel **20u** associated with an internal antenna **40** (described above) may be assembled

to the device **10** upon original manufacture by an OEM and the second panel **20u'** (associated with the external antenna **140**) can be provided as an aftermarket component and/or retrofit kit. Alternatively, the second panel **20u'** can be provided with or assembled to the device upon original manufacture and the first panel provided as an aftermarket component and/or retrofit kit. Still further, the first and second panels **20u, 20u'** may be provided in a kit or package with the device **10** or selectable upon order or purchase to allow a user to employ the particular panel (and associated antenna) he/she prefers. Each antenna **40, 140** can be configured to electrically interface with and/or engage a common signal connection port in the device **10**. The external antenna assembly **140a** may include matching components or circuits as is well known to those of skill in the art. In certain embodiments, the first and second panels **20u, 20u'** are easily interchanged, with the undesired panel antenna being pulled off the device (and, as desired, discarded) and the other panel simply pushed or snapped onto the device to automatically provide the desired electrical interface with the internal circuitry.

Figures 2A-2C illustrate a modular antenna assembly **140a** with an external antenna **140** this is configured as a "fin" **140f**. Examples of conventional fin antennas are well known to those of skill in the art. As shown, the fin antenna **140f** may be held substantially centrally and proximate the top of the device body **10b**. The modular external antenna assembly **140a** is sized and configured to define a second upper rear panel **20u'** that can be used interchangeably with a first panel (which may be an OEM installed panel) such as the panel shown as **20u** above. The assembly **140** can releaseably mount (typically by frictional engagement and/or snapping into place) in lieu of the first panel **20u** associated with the internal antenna **40 (Figure 1A)**. The assembly **140a** can include an internal cavity **141** and an electrical antenna interface connector **142**. The internal cavity **141** may provide an acoustic chamber for a speaker in the device **10**. As shown, the antenna interface connector **142** is positioned substantially centrally proximate a top portion of the upper panel **20u'** so as to be able to contact an underlying signal connector **30** when the panel **20u'** is mounted in position on the body of the device **10**. The external antenna **140** can then engage the internal electronics at the same signal feed as the internal antenna **40** described above. The antenna interface connector **142** can be configured as a finger which includes a conductive lower (leaf) spring member **142c** that can extend inwardly toward the forward surface of the device **10** and compress to securely contact and engage at least

one of the connectors **30**. Other interface connectors and/or configurations may be employed as will be well known by those of skill in the art. In addition, the modular external assembly that provides the external antenna may be configured to provide two different external antennas (not shown).

Figures 3A-3C illustrate a modular antenna assembly **140a** with an external antenna **140** this is configured as a "stub" antenna **140s** that is located at a top portion of the panel and is offset from the center thereof. Examples of conventional stub antennas are well known to those of skill in the art. The modular external antenna assembly **140a** is sized and configured to define a second upper rear panel **20u'** that can be used interchangeably with a first panel **20u.** As before, the assembly **140** can releaseably mount (typically frictionally engage or snap into place) in lieu of the first panel **20u** associated with the internal antenna **40 (Figure 1A)**. The assembly **140a** can include an internal cavity **141** and an electrical antenna interface strip **242** that extends between the antenna **140s** and the interface contact **242c**. The interface contact **242c** may be held on a protrusion **242p** (such as one or two fingers) that extends inwardly a sufficient distance to engage at least one internal connector **30** when the device **10** is held in operative position. As shown, the antenna interface contact **242c** is positioned substantially centrally proximate a top portion of the upper panel **20u'** so as to be able to contact an underlying signal connector **30** when the panel **20u'** is mounted in position on the body of the device **10**. The external antenna **140** can then engage the internal device electronics at the same signal feed as the internal antenna **40** described above. The antenna **140s** may comprise a spiral or coiled length of conductive wire that forms the conductive element with the desired load and impedance (such as about ¼ wave or about a ½ wave load).

Figures 4A and **4B** illustrate an external antenna **140** that is a retractable and extendable antenna **140r**. In this embodiment, a take-up reel **250** can be held in the antenna assembly **140a** and mounted to the panel **20u'** that rotates to wind and unwind a length of conductive rod or wire **140w**. **Figure 4A** illustrates the antenna rod **140r** in an extended position and **Figure 4B** illustrates the antenna rod **140r** in a retracted position. The rod **140r** may be formed of a relatively stiff wire (such as titanium). Other dynamic rod configurations and rod materials may be used.

The electrical interface connection **342** includes a laterally extending strip that contacts the rod **140r** on one side and a metal strip **342c** that wraps over protrusion **342p** on the other side to position the interface contact to engage at least one of the

connectors **30** when in position. The antenna rod **140r** side of the interface **342** may include a spring-loaded edge portion **342e** that is sized and configured to allow the antenna rod **140r** to slide there over and still remain in contact with the rod **140r** (such as via compression force from the antenna). As noted before, additional switchable matching circuitry can be employed to adjust for the impedance differential provided when the antenna rod **140r** is extended rather than retracted. The antenna rod **140r** may be configured as a top-loaded whip and may include a top loaded helical coil or other element and a desired linear length of rod as is well known to those of skill in the art.

In certain embodiments, in the extended position (**Figure 4A**), the antenna rod **140r** may operate with about a half-wave ($\lambda/2$) load. In this situation, the impedance at the output of the antenna feed may rise as high as 600 Ohms. In contrast, in the retracted position, as shown in **Figure 4B**, the antenna rod **140r** may operate with about a quarter-wave ($\lambda/4$) load with an impedance typically near 50 Ohms. Therefore, when the antenna **140r** is in the extended position an L-C matching circuit may be used. The matching circuit (not shown) can be mounted to the rear panel **20u'** and electrically positioned in the signal feed path. Exemplary matching circuits are described in U.S. Patent No. 5,986,607 and U.S. Patent No. 5,856,808, the contents of which are hereby incorporated by reference as if recited in full herein.

It will be understood that, although antennas according to embodiments of the present invention are described herein with respect to wireless terminals, embodiments of the present invention are not limited to such a configuration. For example, antennas according to embodiments of the present invention may be used within wireless terminals that may only transmit or only receive wireless communications signals. For example, conventional AM/FM radios or any receiver utilizing an antenna may only receive communications signals. Alternatively, remote data input devices may only transmit communications signals.

In the drawings and specification, there have been disclosed embodiments of the invention and, although specific terms are employed, they are used in a generic and descriptive sense only and not for purposes of limitation, the scope of the invention being set forth in the following claims. Thus, the foregoing is illustrative of the present invention and is not to be construed as limiting thereof. Although a few exemplary embodiments of this invention have been described, those skilled in the art

will readily appreciate that many modifications are possible in the exemplary embodiments without materially departing from the novel teachings and advantages of this invention. Accordingly, all such modifications are intended to be included within the scope of this invention as defined in the claims. In the claims, means-plus-function clauses, where used, are intended to cover the structures described herein as performing the recited function and not only structural equivalents but also equivalent structures. Therefore, it is to be understood that the foregoing is illustrative of the present invention and is not to be construed as limited to the specific embodiments disclosed, and that modifications to the disclosed embodiments, as well as other embodiments, are intended to be included within the scope of the appended claims. The invention is defined by the following claims, with equivalents of the claims to be included therein.